Conformity Analysis of Cotton Crop using Remote Sensing and GIS

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One of the most important and urgent problems in India is to improve agricultural land management and cropping patterns to develop regional strategies and programmes aimed at increasing the agricultural production together with efficient use of land resources. The information on the spatial distribution and suitability of various types of soils to various types of crops is crucial for planners and agricultural scientists to initiate and encourage farmers to practice cropping systems based on soil potential to various crop categories. In this study the spatial distribution of cotton crop in relation to its suitability based on soil characteristics have been evaluated using RS&GIS techniques for Guntur district of Andhra Pradesh, India. The study had clearly brought out the spatial distribution of cotton crop as derived from satellite data in conjunction with the soil information as derived from GIS techniques is helpful in crop Management options for intensification or diversification.

1. Introduction

Cotton is one of the finest natural fibres available to mankind for clothing from time immemorial. The crop contributes 85% raw material to the industry. Nearly one third of India's export earnings are from textile sector and cotton, alone which constitutes nearly 60% of raw material (CICR, 2001). It is estimated that cotton requirement in India by 2025 is around 140 lakh bales of lint and present production is about 123 lakh bales. This crop is mainly concentrated in four agro-ecological system regions, either as a sole or as an intercrop in cereal or pulse based cropping systems.

Out of the 5.1 M ha of the cultivated cotton crop, 4.1 M ha is predominantly grown in 30 districts, spread over Maharasthra, Andhra Pradesh, Karnataka, Gujarat, Madhya Pradesh Rajasthan, Punjab, Haryana and Tamil Nadu states. The variations in the cotton productivity and production are attributed to the soil, climatic and socio-economic factors besides the market price of the commodities during the in and off-seasons of the cotton crop. Information on potential yield is useful in choosing the strategies of crop management to fill up the yield gaps.

Studies dealing with the regional level potential production are limited mainly because of the non-availability of the relevant data at appropriate scales and the analytical procedures to integrate the data. Satellite-based remote sensing data can provide the in-season spatial information on the extent and distribution of the crops. The ground-based conventional techniques of complete enumeration of the crop estimates are tedious, time consuming and subjective. The information of the spatial distribution of crops as retrieved from satellite data is highly compatible for analysis in GIS environment, which can be ingested into the crop models. The GIS facilitates the computation of regional level products by integrating the relevant factors in a spatial domain. Hence, it is envisaged in this study to integrate RS, GIS and crop models in a synergy to derive information on the potential production of cotton crop, which is useful in yield gap analysis.

The aim of this study is to match the distribution of the cotton crop in relation to its suitability based on the soil characteristics.

2. Study Area:

Guntur district of Andhra Pradesh state, India, and lies between 15°45'-16^{0}50'North latitude and 79°12'-80^{0}55' East longitude on the globe. Climate falls within the hot humid region of the country and it is not more than 40 miles from the Sea. The normal rainfall is 1000mm and July to November may be regarded as the heaviest monsoon period**.** The soils are predominantly deltaic alluvium (29.2%) deep and medium black soils (27.2%), red and rd loamy soils (23.3%), red soil with clay base (8.7%) and costal sands (8.7%).

3. Materials

In this study, soil map on 1:250000 scale, prepared by the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Nagpur, India was used for soil information. IRS-1D LISS-III data was used for generating information on the spatial distribution of cotton crop. The climatic parameters were assumed to be uniform in the entire district. The soil suitability was considered to be the guiding factor for deciding the spatial distribution of cotton crop.

4. Methodology:

The methodology used in the study consists of: (a) Preparation of soil map, (b) Generation of soil suitability map, (c) Estimation of area under different soil suitability classes, (d) Analysis of satellite data and (e) Estimation of cotton area under different suitability classes. The overall methodology followed is illustrated in Fig. 1

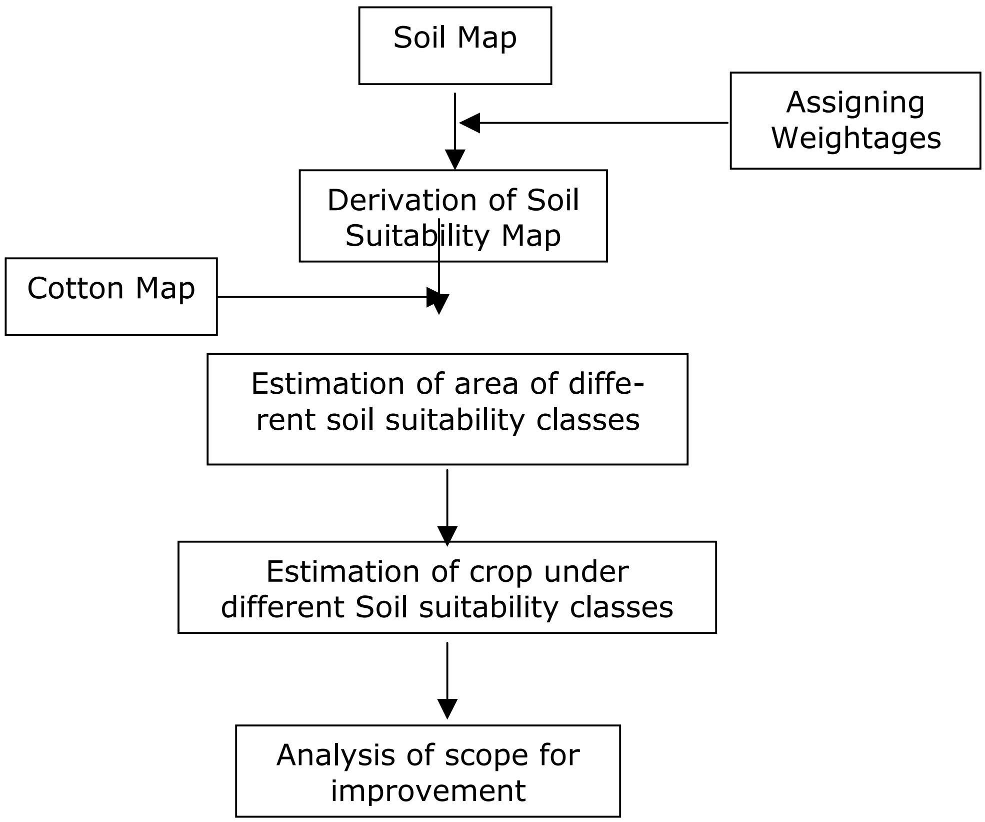

Fig. 1: Flow chart depicting the steps of the conformity analysis

4.1 Preparation of Soil Map:

The soil layer was prepared from the soil maps of NBSS & LUP at 1:250,000 scale. The NBSS & LUP soil map was scanned with 300 dpi and digitized using Arc/Info software to generate a vector layer. The digitized coverage was corrected for all the digitization errors and polygon topology was built. Four attributes namely; soil depth, drainage, texture and available water capacity corresponding to the various soil parameters were added to the Polygon Attribute Table. These attributes were added to store the soil category information for all the spatial units. The appropriate attribute values were then attached to each polygon in the coverage.

4.2 Generation of soil suitability map:

The suitability map was prepared considering the soil requirements for the cultivation of cotton crop. The important pedo-climatic requirements are presented hereunder:

4.2.1Pedo-climatic requirements of cotton:

The physico-chemical properties of soils such as depth, texture, available water capacity (AWC), pH, cation exchange capacity etc., are the important soil characteristics in land evaluation that affect the yields under specific climatic and site conditions. Deep (>100 cm), well drained, gentle slopy soils with clay to fine loamy texture are most preferred soil environments for the growth of cotton crop. The combined effects of these parameters are to be looked into in a holistic approach rather than comparing individual characteristics with yield. In order to have realistic idea about yield contributing soil characteristics / qualities, data on level of crop management and the socio-economic data are required.

Cotton is mostly concentrated (under rainfed agriculture) in semiarid to dry sub-humid areas with average annual rainfall varying from 700 to 1200mm, with growing season rainfall varying from 650 to 900mm. The mean temperature during the growing season ranges from 21 to 28^0 C and mean relative humidity during the growing season varies from 45 to 84 per cent. The crop is grown in the places where the moisture availability period (LGP) is 135 to 180 days (NBSS & LUP, 1994).

4.2.2 Approach for deriving suitability maps:

Deriving soil suitability zones can be considered as a Multi Criteria Decision Making problem, wherein the criteria / parameters controlling the soil suitability are soil depth, drainage, texture and available water capacity, each of which in turn contain different categories (Jack, 1999 and Sys et al., 1991). These criteria and sub-criteria are of varying importance to the decision-maker. Consequently, information about the relative importance of the criteria is required. This is achieved by assigning a weight to each criterion. The derivation of weights is the central step to elicit the decision maker's preferences.

After the weightages are derived, these evaluation criteria have to be integrated using multicriteria decision rules. The decision rules provide the basis for ordering the decision alternatives and for choosing the most preferred alternative.

4.2.3 Multi Criteria based Decision Making:

The GIS based method for solving Multi Criteria based Decision Making problems involves the following steps:

1. Defining the set of evaluation criteria (map layers) and the set of feasible alternatives.
2. Standardizing each criterion map layer.

3. Defining the criterion weights; that is a weight of “relative importance” is directly assigned to each criterion map.
4. Construction of the weighted standardized map layers; that is multiplying the standardized map layers by the corresponding weights.
5. Generation of the overall score for each alternative using the add overlay operation on the weighted standardized map layers.
6. Ranking the alternatives according to the overall performance score; alternatives with higher scores are most suitable or preferred.

4.2.4 Implementation of Soil Suitability Map:

The soil suitability map is derived by the following steps:

1. Ranking of soil parameters and categories according to their level of importance
2. Deriving weightages for the soil parameters and their categories using the Rank Sum method
3. Integrating the soil parameters and deriving a composite layer by applying the above derived weightages using the Simple Additive Weighting method
4. The composite grid is divided into four suitable classes by reclassifying the composite layer using equal interval classification method.

4.2.4(i) *Ranking Soil Parameters and categories*:

The soil suitability map was derived from the base soil map of NBSS & LUP at 1:250000 scale. Based on the guidelines provided by the agronomic experts, the soil parameters and the categories within them were arranged in rank order; that is every parameter / category under consideration is ranked in the order of the decision maker’s preference. Straight ranking was used i.e., the most important = 1, second important = 2 etc.

4.2.4. (ii) *Deriving weightages*:

Once the raking is established, numerical weights are generated from the rank-order information using the Rank Sum method. Rank Sum weights are calculated according to the following formula:

$$W_j = (n - r_{j)\,/}\ \Sigma (n - r_k+1) \qquad \_\_\_\_\_\_\_\_$$

Where w_j is the normalized weight for the j^{th} criterion, n is the number of criteria under consideration, (k = 1,2….n), and r_j is the rank position of the criterion. Each criterion is weighted $(n-r_j+1)$ and then normalized by the sum of all weights, that is, Σ $(n-r_k+1)$.

4.2.5 *Integration of soil parameters:*

The various soil parameters with their weightages need to be integrated to derive an overall assessment of the alternatives. Additive decision rules are the best known and most widely used methods in GIS based Multi criteria decision-making. Simple Additive Weighting method is used for the integration of soil parameters.

This method integrates the data and information on alternatives and decision maker's preferences into an overall assessment of alternatives. This technique also referred to as Weighted Linear Combination (WLC) method which is the most often used technique for tackling multi- attribute decision-making problems. This method is based on weighted average of the weights assigned by the decision-maker to each attribute. A total score is obtained for each alternative by multiplying the importance weight assigned for each attribute by the scaled value given to the alternative on that attribute, and summing the products over all attributes. When the overall scores are calculated for all the alternatives, the alternative with the highest overall score is chosen. Each alternative (Ai) is evaluated as follows:

$$A_i = \Sigma (w_j x_{ij})$$

Where x_{ij} is the score of the i^{th} alternative with respect to the j^{th} attribute, and the weight w_j is normalized weight, so that $\Sigma (w_j) = 1$. The weights represent the relative importance of the attributes. The most preferred alternative is selected by identifying the maximum value of Ai (I = 1,2,…m).

4.2.6 *Reclassification of composite layer into suitable zones*:

The composite layer generated above contains the overall scores for all the alternatives. Alternatives with high overall scores are more suitable. The entire range of values in the composite layer is divided into 4 classes using the Equal Interval Classification method. The four classes are Most suitable, Highly suitable, Moderately suitable and Least suitable.

4.3 Estimation of area under different suitability classes:

The soil suitability map derived as above was then subjected to the 'dissolve' operation based on the suitability class attribute, so that adjacent polygons having the same suitability class are merged. By using the statistics operation with 'sum area' area corresponding to each suitability class is obtained.

4.4 Analysis of satellite data:

The satellite data of IRS 1D LISS – III of November, 2000 was classified by total enumeration approach employing the supervised maximum likelihood classifier algorithm (Krishna Rao, et al., 2000), using ERDAS IMAGINE-8.5 software. The satellite data was registered with the soil map to carry out the overlay analysis. The classified raster data of cotton was converted to vector format, which contains information about the spatial distribution of the crops within the district.

4.5 Estimation of area of cotton under different suitability regimes:

The cotton mask coverage containing the areas where cotton is grown is overlayed with the soil suitability map using the union operation. The union operation retains the shapes and attributes of both the input layers. Therefore, the resultant layer provides the information about how the cotton crop is distributed across the various soil suitability zones. With the help of the statistics operation on the cotton-soil overlaid coverage, the amount of cotton growing area in each suitable zone was derived.

5. **Results & Discussion**

5.1 *Weightages of the parameters and categories:*

The ranks assigned to the parameters and categories were converted into weightages by using the Rank Sum method as described in the methodology. These weightages were combined by the Simple Additive Weightage method to arrive at the integrated weightage for each polygon. These weights were further thresholded based on the equal interval classification and five categories of suitability derived.

The ranks and weightages of the parameters and their categories are given in tables 1 and 2:

Table 1: Ranks and weightages of the soil Characteristics

Parameter	Rank	Normalised Weight	Scaled Weight
Available Water Capacity (AWC)	1	0.4	100
Soil depth	2	0.3	75
Texture	3	0.2	50
Drainage	4	0.1	25

Table 2: Ranks and weightages of the soil characteristics

Parameter	Category	Rank	Normalised Weight	Scaled Weight
Soil depth	Very deep	1	0.4	100
	Deep	1	0.4	100
	Moderately deep	2	0.3	75
	Moderately shallow	2	0.3	75
	Shallow	3	0.2	50
	Very shallow	4	0.1	25

		4	0.1	25
Drainage	Well drained	1	0.5	100
	Mod. Well drained	2	0.33	66.7
	Imperfect	3	0.167	33.3
	Excessive	3	0.167	33.3
Texture	Clay	1	0.4	100
	Clayey	1	0.4	100
	Gravelly clay	2	0.3	75
	Loamy	3	0.2	50
	Gravelly loam	3	0.2	50
	Sandy	4	0.1	25
Available Water Capacity (AWC)	Very high	4	0.4	100
	High	4	0.4	100
	Medium	3	0.3	75
	Low	2	0.2	50
	Very low	1	0.1	25

5.2 Analysis of satellite data:

The analysis was carried out for one typical districts of Andhra Pradesh, viz., Guntur. The vectorised cotton crop map of Guntur district was presented in fig. 2. The cotton acreage in this district was 134558 hectares.

5.3 Conformity analysis:

The conformity analysis was carried out in two steps. The first Step comprised of delineating the total arable land into different suitability classes according to the normalized weights derived, explained as above. In the second step, the vectorised cotton layer, as derived from the satellite data was overlaid and the areal extent of cotton crop under different categories were delineated and quantified. The cotton crop under different suitability classes for the study area is presented in Table 3.

Table 3: Area of cotton under different suitability classes of the three districts

District	Suitability Class	Total Cotton Area(Ha)	Proportion of total cotton (%)
Guntur	Most Suitable	27435.73	20.39
	Highly Suitable	65045.12	48.34
	Moderately Suitable	36292.33	26.97
	Least Suitable	4381.95	3.26
	Unsuitable	1402.75	1.04

5.4 Assessment of the conformity analysis:

The assessment of the conformity analysis in terms of the total cotton cropped area vis-à-vis their suitability classes are presented hereunder:

The soil suitability map for cotton crop, spatial distribution of cotton crop under different suitability classes, and their overlay are presented in Figs. 2, 3 and 4, respectively. The analysis revealed that in Guntur district, 20.39% of the total cotton crop is under most suitable soil class and 48.34% is under highly suitable class. A substantial portion of 26.97% is under moderately suitable class, 3.26% in least unsuitable and 1.04% in highly unsuitable areas. The average yield of the Guntur district is substantially affected because of a significant proportion of cotton crop under moderately suitable class. Economic levels of agricultural production can be obtained by (a) cultivating cotton in most and high suitable pockets of the district or (b) growing more suitable crops in the areas that are moderately suitable for cotton.

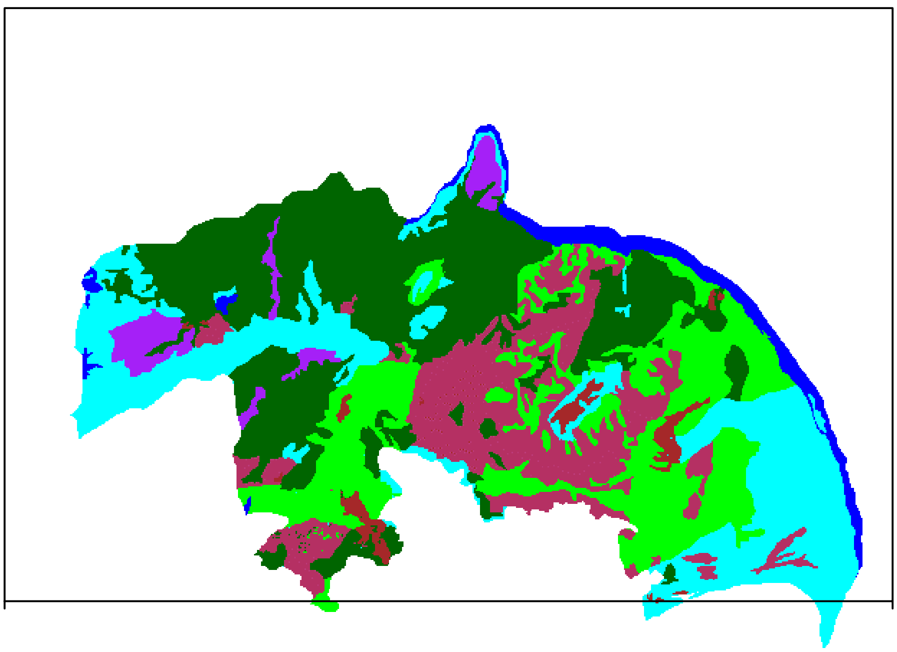

Fig 2: Soil suitability map for cotton crop of Guntur district

Most suitable
Highly suitable
Moderately suitable
Least suitable
Forest
Rock outcrops
Water

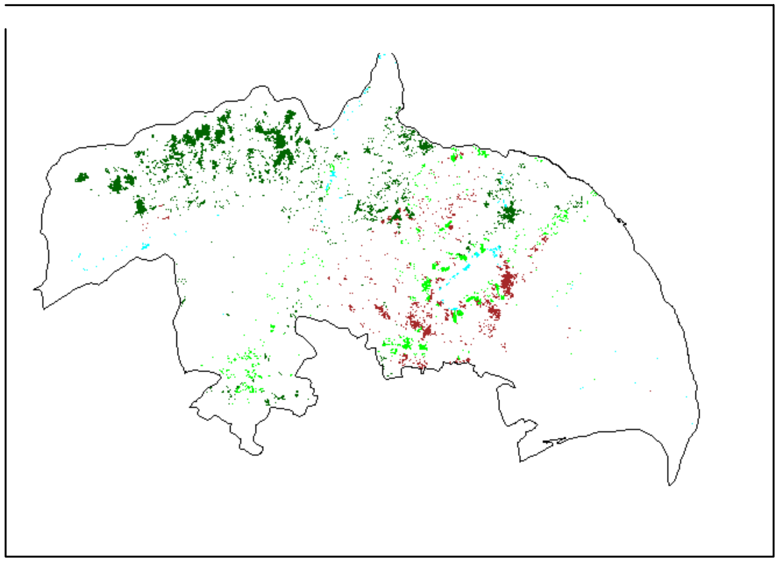

Fig.3. Spatial distribution of cotton crop of Guntur district under different suitability classes

Cotton-most suitable area

cotton-highly suitable area

Cotton-moderately suitable area

cotton –least suitable area

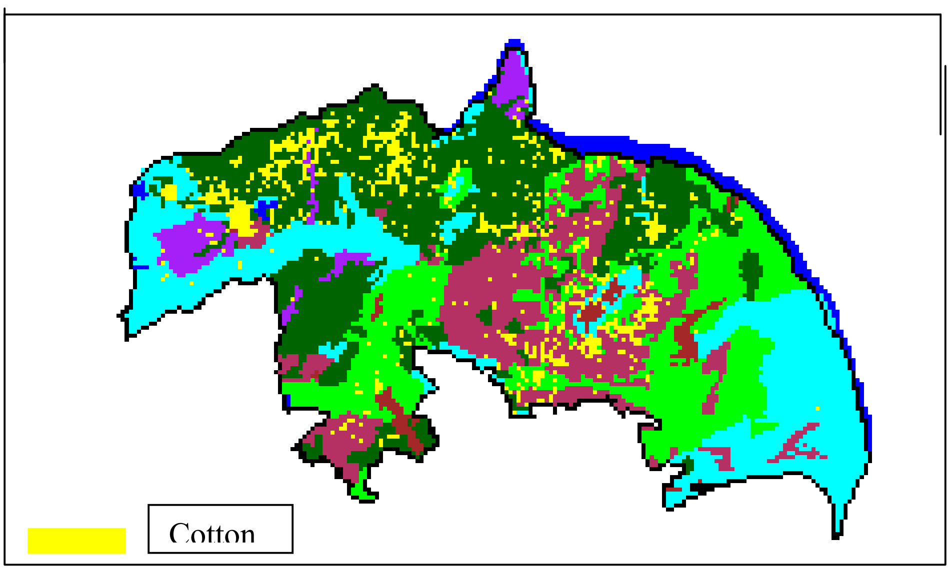

Fig 4: Overlay of spatial distribution of cotton of Guntur district on different cotton suitability Classes.

6. **Summaries and Conclusion**:

The distribution of the cotton crop provides us the choice of the strategies to increase the production through horizontal or vertical approaches. In Guntur district, the proportion of land under moderately suitable regime needs to be diversified for crops other than cotton that suit the pedo-climatic requirements. The study had clearly brought out the spatial distribution of cotton crop as derived from satellite data in conjunction with the soil information as derived from GIS techniques is helpful in crop Management options for intensification or diversification.

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